Irrigation Management in Humid Regions

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INTRODUCTION

Irrigation management includes deciding how much irrigation water to apply, and when to start and stop the irrigation. For any management decision, the choice of operation depends on what one wants to do. The simple answer may appear to be "put on some water," but the choice is often more complex. For instance, one can attempt to maximize net return, minimize operating costs (especially labor), maximize yield, optimize limited water supply, minimize environmental risk, or optimize production under a limited irrigation system capacity. All of these may be constrained by regulations. In general, water supply and irrigation costs control the economics, so the best result is obtained by maximizing yield on all irrigated land, usually called the land-limiting case. In simple terms, one irrigates to avoid crop water stress.

Important irrigation system parameters for consideration include the irrigation application rate per unit area, the total system supply rate, and for moving systems, the velocity. At a given pumping rate, moving machines cover their entire irrigated area in a given return time. If more application depth is required, the system can be set for a slower velocity, which trades increasing depth for longer operating times. For solid-set systems, including sprinklers and drip, increasing application depth is achieved by operating the system longer.

All these considerations apply for both arid and humid areas, and are covered briefly here so that the reader may interpret the article without referring elsewhere. For the following, the discussion concentrates on the particular case of humid areas, contrasting with the conventional, more-arid case.

CONTEXT OF HUMID AREAS

Humid area climate differs from arid area climate in several ways. First is the defining characteristic, humidity. In humid areas, the dew point often equals the early morning air temperature, unlike most arid areas, and the difference in vapor pressure deficit affects crop temperature. Along with higher humidity comes, generally, more clouds. These reduce the total daily solar radiation, which reduces the evaporative demand. Finally, humid areas generally receive more rain than arid areas. The possibility of rain occurring just after an irrigation can complicate an irrigation manager's decision in two important ways beyond applying unnecessary water. One is the risk of waterlogging a crop and causing damage by lack of aeration. The other is risk of leaching nutrients or other chemicals.

On the other hand, during periods without rain, the weather in humid areas can be similar to that in arid areas. Rain-free days are generally less cloudy, which then means more nearly clear-sky solar radiation and higher evaporative demand. Also, air temperature may be higher and humidity lower than averages, which include the cooler wet days. Similarity between humid and arid regions during periods of drought, which can occur in as little as two rainless weeks, creates additional challenges for irrigation managers in the humid region. Strategies optimized assuming the next rainfall is imminent can fail if the next rain occurs four or six weeks later.

Another consequence of higher rainfall amounts in humid areas is a radically different water supply system than in arid regions. There are few large water projects with objectives to provide irrigation water, and no extensive water districts to manage the allocation. Therefore, most water supplies must be farmer-developed. Historically, these were farm ponds retaining runoff or streams from either of which farmers pumped directly. Where groundwater was available, wells were added to provide backup to ponds, and where extensive aquifers existed, irrigation expanded using high-capacity wells. Since they were developed individually, farmer water supplies were not regulated, or if so, minimal information was required for permits. As a direct result of this history of irrigation development, little knowledge exists regarding the water withdrawals, irrigation capabilities, or area

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irrigated in most humid areas. A useful case study of the difficulties caused by this lack of information can be found in southwestern Georgia.[1]

IRRIGATION SCHEDULING EMPLOYED IN HUMID AREAS

As mentioned earlier, in the usual (land-limiting) case, one achieves the optimum economic return by maximizing yield on all irrigated land, which is achieved by irrigating to avoid crop stress. This can be done in several ways, all of which have been used in humid areas of the eastern United States. One can sense the water status of the crop, measure soil moisture, or compute the soil water balance. There are many variations on these three approaches. Even the fixed time-clock control of lawn and other turf irrigation systems (if adjusted properly) is an attempt to maintain soil moisture in a range suitable for plant health.

Plant Stress Methods

The most well-known indicators of plant water stress are visual: rolled or drooping leaves and color change. However, by the time these conditions occur in crops, yield has already been reduced. Therefore, scientists looked for earlier indicators of water stress. One early stress measurement is the infrared thermometer, which is a noncontact device and is sensitive to longwave ($\sim 10\,\mu m$) radiation, that measures the average temperature in the field of view. For theoretical reasons, the difference between the canopy and the air temperature is the important measure, but the vapor pressure deficit is an important factor in the interpretation of the temperature difference. In humid areas, the canopy temperature may be somewhat higher relative to the air temperature than in arid areas. Both air temperature and vapor pressure deficit are taken into account with the crop water stress index, or CWSI, but research in the humid southeastern United States indicates that additional work is needed before this method can be widely applied.

Other plant stress monitors have been proposed and are included here for reference. Near-infrared (NIR, $\sim 1\,\mu m$) photography and remote sensing have been used in research environments, but other stresses, such as disease or poor nutrition, can also cause NIR responses. Some research has monitored leaf water potential using the pressure chamber or the leaf press. Sap flow devices have been used to measure water movement into plants, particularly for perennial plants. Since water flow is in response to plant water needs and soil water supply, the device can detect periods when these are limited. A recent report from Israel suggested that minute changes in leaf thickness could be sensed as an indication of plant water status. All of these devices have been useful in research for assessing plant water stress, but expense and/or complexity have limited their application in production.

Successful use of any plant water status measure depends on being able to identify some trigger point at which to initiate irrigation. For the infrared-thermometer-based CWSI method, some have determined responses to initiation at one value or another, say 0.5 in the range 0 (no stress) to 1.0 (complete stress). However, as mentioned earlier, using any absolute value of the CWSI in humid areas requires additional research or possibly local calibration. In addition, scheduling irrigation based on observing stress is subject to an inherent limitation in that it cannot successfully predict what time in the future one needs to irrigate. In practice, experience can overcome this limitation.

These local calibrations may be avoided using an innovative approach to initiating irrigation using an indicator of the variation in soil water that exists across a field. In this approach, an infrared thermometer is read as it is moved across a field, as from the window of a moving vehicle. Irrigation is triggered when the variation in temperature in the series of measurements exceeds a certain amount. Basically, this approach uses the driest area of the field as an indicator; when it gets dry, the rest of the field would not be far behind, so irrigate soon. Because the air temperature, vapor pressure, and other factors are all reasonably constant during the scan, this method can use the actual crop temperature.

Soil Moisture Methods

Research has shown that plants can extract water from soil when it is held somewhere between the field capacity, which happens after free drainage following rain and is between -0.01 MPa and -0.03 MPa soil water potential, and the permanent wilting point, usually assumed to be at -1.5 MPa soil water potential. These concepts have been debated, but use has shown them to be useful approximations. Most of the water contained in the soil is held between the field capacity and -0.1 MPa. For this reason, tensiometers, which can measure water between 0 MPa and -0.08 MPa, can monitor soil water over a range important to irrigation.

Researchers in the southeastern United States have employed tensiometers, with irrigation being triggered when the potential at 0.3-m depth gets drier from -0.02 MPa to -0.05 MPa. Important considerations include the depth, the position of the sensor relative to the plant row and roots, and also the crop species. Tensiometers must be serviced periodically to remove air and ensure that they have not gotten out of range, which causes unpredictable readings. They must also be monitored frequently in sandy soils because the water removed from the soil in a day might cause the readings to go out of range.

Electrical resistance devices have been embedded in the root zone to measure soil water potential indirectly, using the known relationship between water content and electrical resistance of gypsum. Advantages of these devices are low maintenance and adaptability for reading with simple meters or data loggers. With experience, managers can use these simple devices to indicate that the soil is becoming too dry for continued plant growth.

The other measure of soil moisture is water content. As mentioned earlier, the water content and potential are related through the water-holding capacity function, which may differ for each soil and soil layer. If this relationship is known, soil water content (SWC) sensors can be used to sense soil moisture for irrigation purposes, by determining the water content corresponding to the field capacity and wilting point. Water content can be expressed per unit volume or per unit weight. The only practical method that produces a value per unit weight is the gravimetric technique, in which a sample is weighed, dried, and weighed again. If this technique is used, the mass of soil per unit volume in the original state, or bulk density, must be known to convert to a volume basis. Knowing the water content on a volume basis adds to the irrigation manager's tools because the difference between the water content and the wilting point is an indication of how much water remains, and the difference between field capacity and the water content is how much can be applied at the time of the measurement. Clearly, soil moisture measurements must represent the water content of the effective root zone for this technique to be useful, and the root zone thickness changes with type and usually increases with age of the crop.

Water Balance Techniques

The checkbook-type water balance method has been known for nearly 50 yr. This direct analog to a bank checkbook uses rain and irrigation as credits and evapotranspiration (ET) as a debit to maintain a water content between the field capacity and wilting point for the root zone. One can adjust the rainfall for runoff and drainage below the root zone. Availability of ET data has been the main problem using this technique in the southeastern United States. Evaporation pans have been used, with research testing whether screened or open pans are most reliable.

A physical model of the checkbook method has been implemented using an evaporation pan directly. For this, a calibrated scale is placed on the pan (usually a screened pan) with indications for a full and an empty rooting zone. An inexpensive, recent implementation uses a large washtub specially fitted with a float attached to a flag visible from some distance. When the water level has dropped to a point equivalent to the soil water refill amount, the flag passes a preset mark and irrigation is indicated. An overflow hole is set at a level representing full SWC. Since the device is placed in the field of sprinkler irrigated crops, it receives both irrigation and rainfall, filling to the overflow mark with excessive rain or

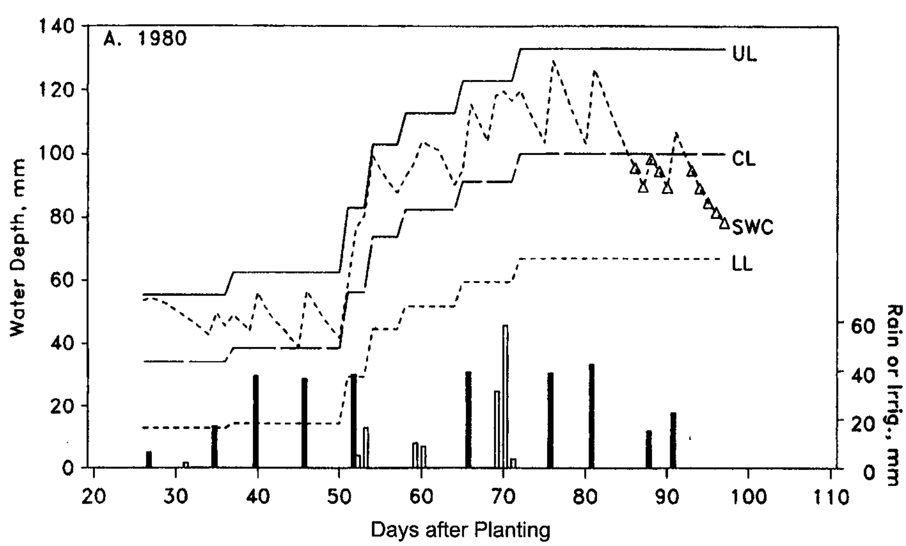

Fig. 1 Water balance technique illustrated. Source was computer-based method in Camp and Campbell, 1988. The lines labeled UL and LL are the upper and lower limits of available water within the root zone. The line CL was the irrigation control point, here at 50% management-allowed depletion. The line SWC is the computed SWC, with triangles flagging the need to irrigate. Solid bars indicate irrigation; open bars indicate rain.

simply adding to the pan as rain and irrigation partially refill the soil and pan.

A computer model of the water balance is simply an automated version of the manual and physical methods mentioned earlier. Usually, ET is calculated from weather station data for temperature and solar radiation, but if ET data were available in published reports, it could be entered. Some computer-based methods use the best available information, starting with measurements, then calculations from weather station data, then calculations from forecast weather, and for predictions beyond the forecast period, historical data. Fig. 1 illustrates the water balance technique. Note the increased water-holding capacity of the profile as the root zone expanded during the season. Up to ~ 85 days after planting, the irrigation in this case was scheduled to successfully control the SWC above the CL line. After that time, the SWC fell below the control limit, and the computer program flagged the line with triangles to indicate the need for irrigation.

Common Considerations

In all of the previous soil-based methods, some decision must be made about the allowable range of soil moisture. Seldom does an irrigator want to allow the soil moisture to drop very close to the wilting point; most trigger points are approximately 30%–50% depletion of available water-holding capacity, for the sake of insurance. Conversely, if irrigation fills the soil rooting zone to field capacity, and rain falls soon after, then the root zone can be subject to aeration problems, and this free water (rain) is lost through runoff or drainage. This choice of management-allowed depletion depends on the probability of rainfall and the likely amount that could be tolerated or used. In this regard, humid-area management is different than arid-area management. The range over which the manager can control soil moisture may need to be restricted to allow for the higher chance of rain.[2]

These requirements, a narrow range for deficit irrigation and inherent limits of the soil water storage, support using frequent, small irrigations rather than less-frequent, large ones. This can lead to a higher fraction of water evaporated directly from the soil surface, which is wet more frequently in the case of sprinkler irrigation, and to increased disease incidence when susceptible crops are frequently wetted. The combination of these considerations brings more interest in buried drip irrigation, which can, if so designed, irrigate frequently, yet keep the soil surface mostly dry.

All measurements represent the area where the measurements are made, but spatial variation will cause any measurement to be unrepresentative of the entire area in most fields. Assuming the field is irrigated the same throughout, how many measurements are needed to represent the entire field? There is no simple answer to this question, nor is there one for the trade offs when distinctly dissimilar soils exist all in one irrigation management unit.

Comparisons

A multi-state study of irrigation scheduling methods concluded that, if properly employed, tensiometers, evaporation pans, and computerized water balance methods, all could be used in the southeastern United States. Tensiometers had one advantage in that they were fairly universal, requiring little calibration. On the other hand, they required significant labor for reading and maintenance. Evaporation pans were also labor-intensive. Computerized water balance models were data-intensive and occasionally needed adjustment of the SWC to eliminate accumulated errors, but were much more amenable to forecasting future irrigation needs.

TECHNICAL ABSTRACT

During the long history of irrigation, management of irrigation systems, which includes deciding how much irrigation to apply and when to do it, has been the subject of much study. Most of this work has been done in primarily arid areas, where the development of irrigation started earlier. However, current trends include increasing irrigated areas in humid regions, for which the contrasting climatic conditions require correspondingly different management techniques. In addition to having higher humidity, humid areas are generally more cloudy (lower solar radiation and thus lower evaporative demand), receive more rainfall, and tend to be cooler on average. However, during even short droughts, the conditions may be quite similar to those in arid regions. Dynamic weather complicates the management of irrigation systems in humid regions, forcing managers to trade off the possibility of rain against the need to leave storage space for potential rain by controlling a relatively narrow range of management-allowed depletion. Doing so can be achieved more easily using frequent, light irrigations instead of less-frequent, heavy ones commonly used in arid regions. Case studies of irrigation management in the southeastern United States serve to illustrate the common management methods, which include tensiometers, evaporation pans, and computer-based water balances. Continuing trends of increasing irrigated area and increasing interest in precision agriculture may combine to focus on spatially variable irrigation management in humid regions.

INTERPRETIVE SUMMARY

Irrigation management includes deciding when to apply irrigation, and also how much to apply. Making these choices in humid regions is somewhat more complicated than in arid ones, primarily because of the possibility of receiving rain shortly after an irrigation. Besides being wasteful, this possibility also carries a risk of drainage and runoff carrying nutrients to groundwater or streams. Managing irrigation to save some room in the soil for possible rain requires a careful balance between crop needs and soil capacity, which can be limited by sandy soils or shallow rooting depths. Management methods leave storage space for potential rain by controlling a relatively narrow range of management-allowed depletion. Doing so in humid regions can be achieved more easily using frequent, light irrigations instead of less-frequent, heavy ones commonly used in arid regions. Case studies of irrigation management in the southeastern United States showed that common methods, which include tensiometers, evaporation pans, and computer-based water balances, can all work. Increases in irrigated area and interest in precision agriculture may combine to focus on spatially variable irrigation management in humid regions.

CONCLUSION

At the current time, two trends in irrigation are apparent. While they may also exist elsewhere, they are somewhat recent in the southeastern United States. The first is the simultaneous increase in irrigated area and increased competition with nonfarm users for water resources. This leads to both a less-than-optimal water supply and higher valuation of the water resource. Therefore, additional questions arise. If one cannot irrigate all the land, where should the water be used to greatest advantage? Should it be used only on high value crops? Should it be applied suboptimally to all the land? Or should the second trend, interest in precision (site-specific) agriculture, be extended to irrigation, so that each individual soil in a field could be irrigated optimally, or less-productive soils be left rainfed while productive soils are irrigated optimally? These questions are currently of increasing interest to researchers. Should the southeastern drought of 1998–2002 continue, they will likely be of increasing interest as well to producers.

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